Astrophysical light scattering problems (PAP316)
Lecture 2c

Microwave scattering in planetary science

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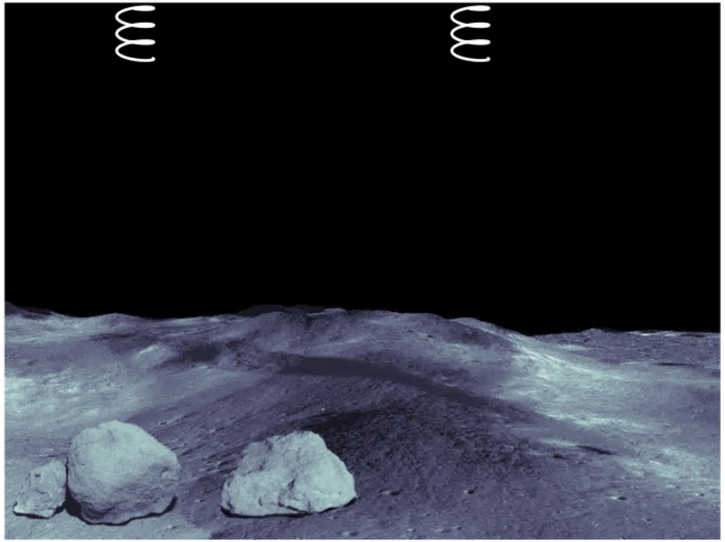
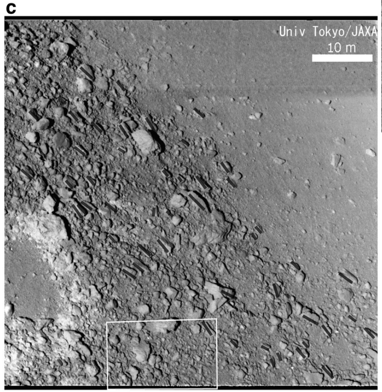
Radar echo from planetary surfaces



Bennu
39.5 m



Itokawa
53 m

"OC" and "SC" polarizations

- **Smooth surfaces:** Specular reflection –> All echo in the *opposite-circular* (OC) polarization than the transmitted signal

- **Rough surfaces (wavelength-scale surface roughness or boulders):** Quasi-specular + diffuse scattering –> Echo partly in the OC polarization and partly in the *same-circular* (SC) polarization

Radar cross section:

$$\sigma_{Pol} = \frac{4\pi R^4 \lambda^2 P_{rx,Pol}}{P_{tx} A_{eff}^2}$$

Radar albedo:

$$\hat{\sigma}_{Pol} = \frac{\sigma_{Pol}}{A_{proj}}$$

One-parameter definitions for surface roughness

- Traditionally used parameters for surface roughness:
  - Circular-polarization ratio (μ_C), typical values 0-1.0
  - Backscatter gain factor (g), typical values 1.2-1.5
  - Surface slope parameter (C or s), typical values 0.1-0.8

$$\mu_C = \frac{\sigma_{SC}}{\sigma_{OC}}$$

$$g = \hat{\sigma}_{OC}/R_F$$

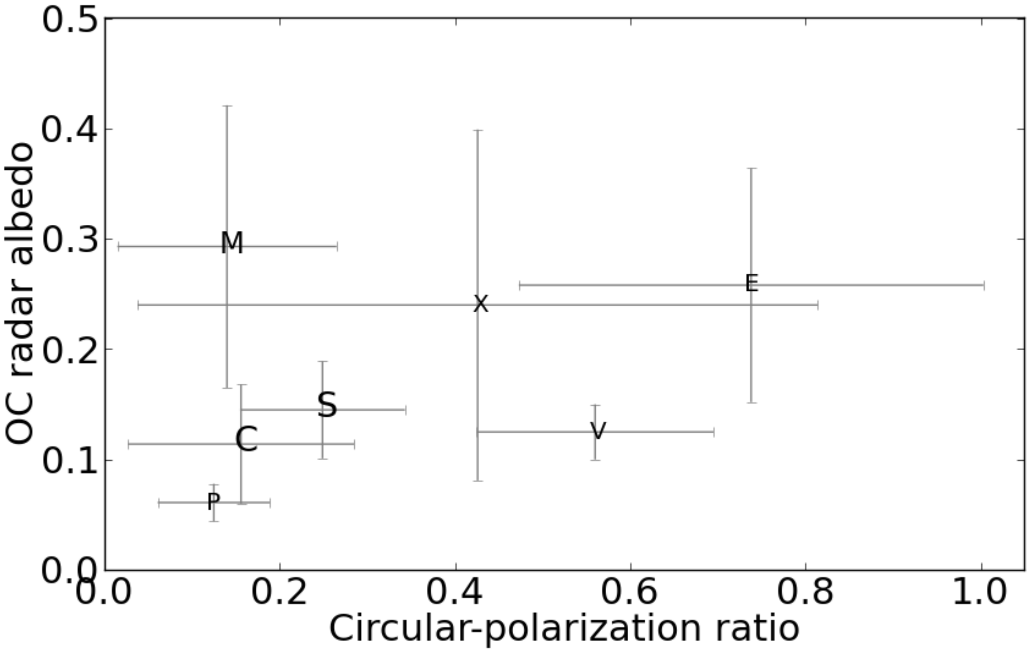
[$g = 1$ for a smooth surface]

$$g \geq 1$$

$$R_F = \left|\frac{\sqrt{\varepsilon}-1}{\sqrt{\varepsilon}+1}\right|^2$$

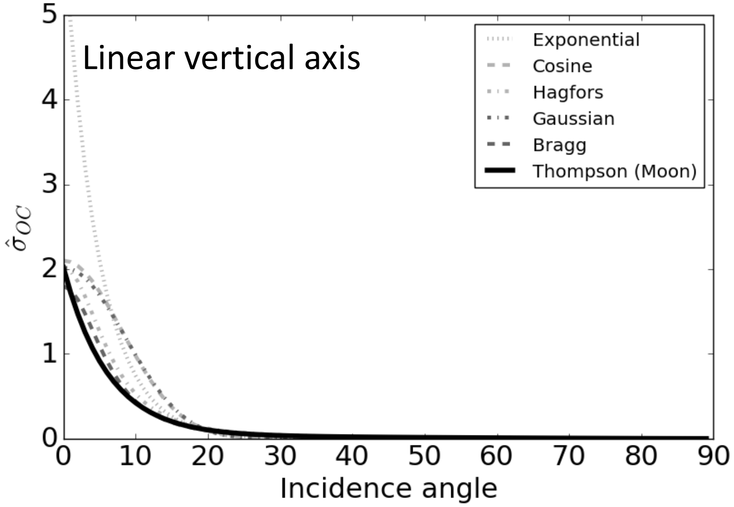
[ε : electric permittivity]

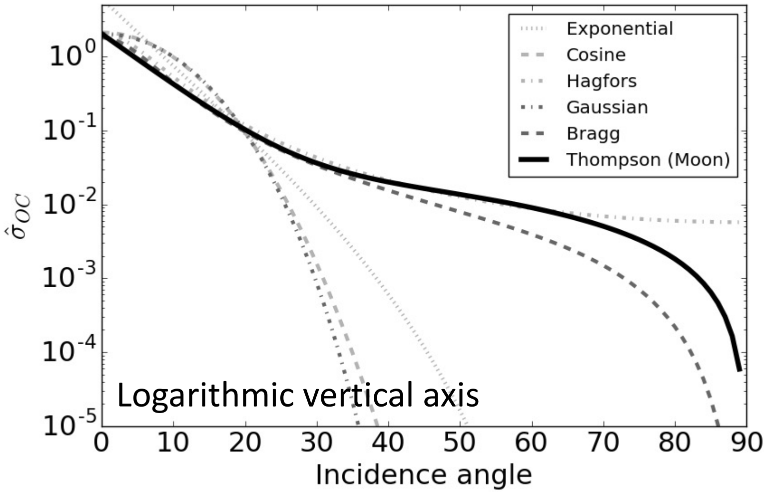
CPR DEPENDS ON THE TAXONOMIC TYPE?



Understanding radar scattering

- Multi-parameter problem: The size, shape, and material of wavelength-scale particles on/in asteroid surfaces play a role in radar scattering as well as the structure of the sub-surface
- Lunar radar analysis has a long history that can help us to understand also radar scattering in asteroid surfaces
- Multi-wavelength comparative analyses can provide constraints
- Modeling work is crucial for understanding how to interpret the radar data

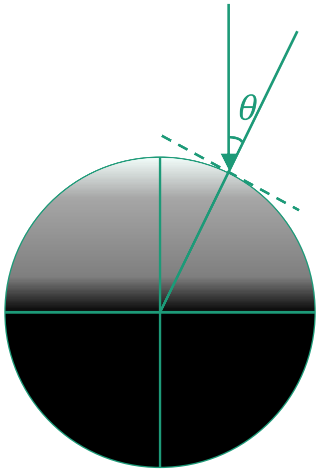




Radar scattering laws

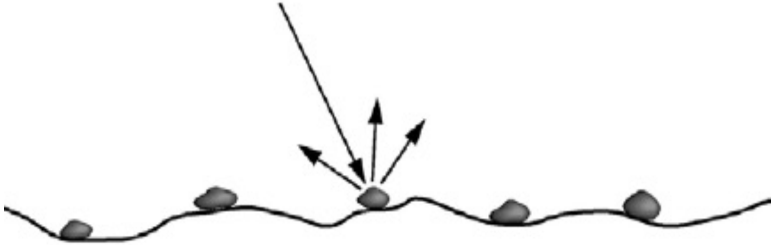
On the left: Backscatter coefficient as a function of the incidence angle

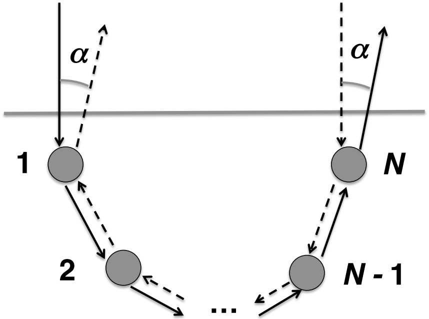
Several radar scattering laws have been developed (with different conditions)



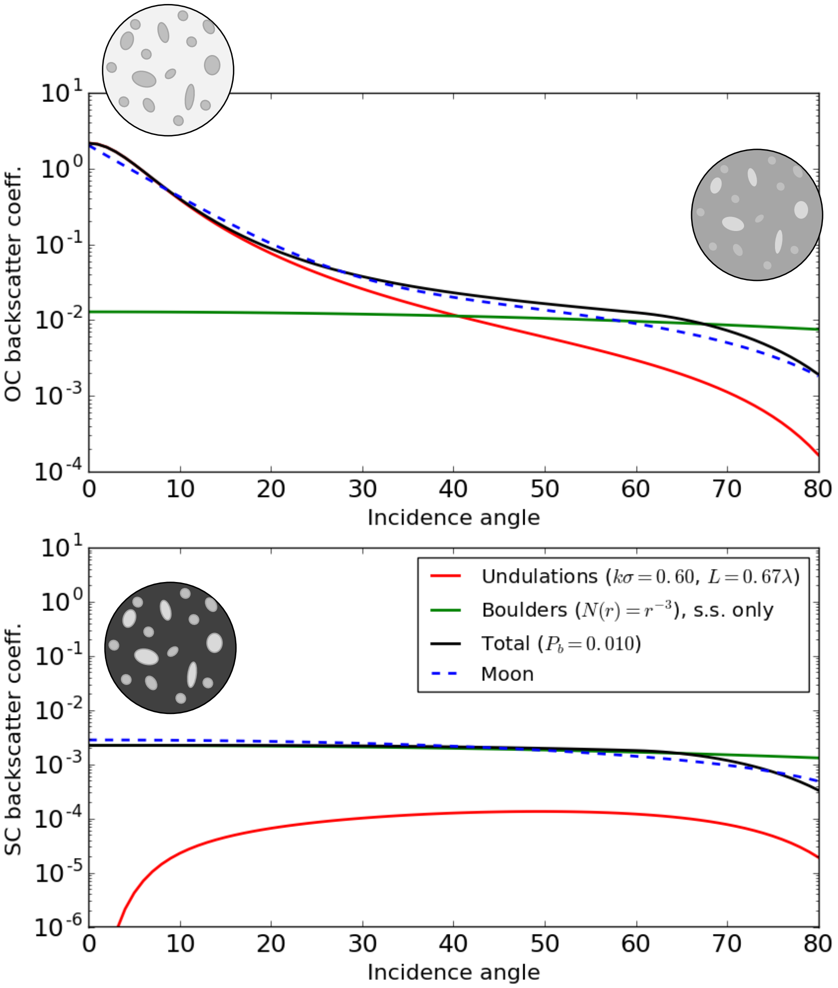
Also: Considering only surface undulations is not enough!

Scattering by particles





Could the sub-surface be studied by a more rigorous analysis of the echo's phase?



m-chi decomposition

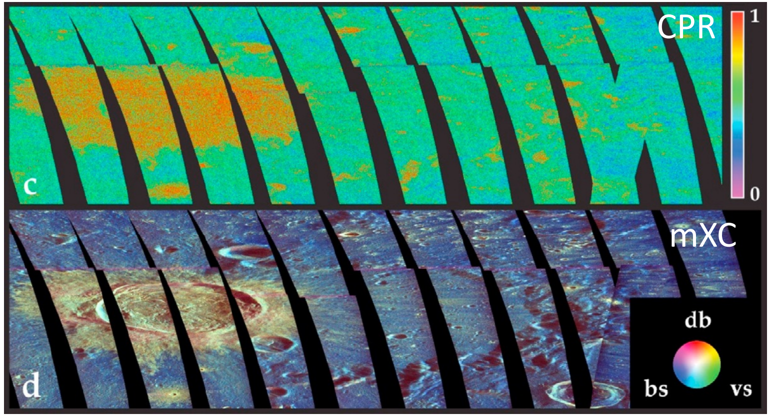
$$\text{Red} = [mS_1(1 + \sin 2\chi)/2]^{1/2}$$
$$\text{Green} = [S_1(1 - m)]^{1/2}$$
$$\text{Blue} = [mS_1(1 - \sin 2\chi)/2]^{1/2}$$

$$m = \frac{\sqrt{S_2^2 + S_3^2 + S_4^2}}{S_1}$$

Degree of polarization

$$\chi = \frac{1}{2} \arcsin\left(\frac{S_4}{mS_1}\right)$$

Degree of ellipticity



[Raney et al. 2012, JGR 17]

Is it double scattering?

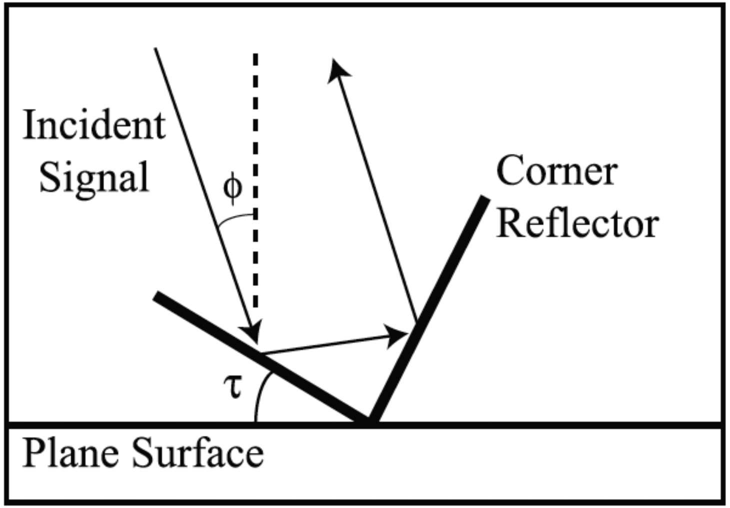


Figure 6. Diagram showing scattering geometry for a corner reflector. The vertical dashed line is the normal to the background plane surface.

Campbell et al. (2012)

We denote the ratio of HH- to VV-polarized backscattered power for a dihedral pair, or suite of such features, as α_D. For an ideal dihedral feature, σ^0_{HV} is negligible, and β is -1. Under these conditions,

$$Re[S_{HH}S^*_{VV}] = -\sqrt{\sigma^0_{HH}\sigma^0_{VV}} = -\sigma^0_{VV}\sqrt{\alpha_D} \quad (14)$$

and the CPR can be simplified from equations (7) and (8):

$$\mu_c = \frac{\left(1+\sqrt{\alpha_D}\right)^2}{\left(1-\sqrt{\alpha_D}\right)^2} \quad (15)$$

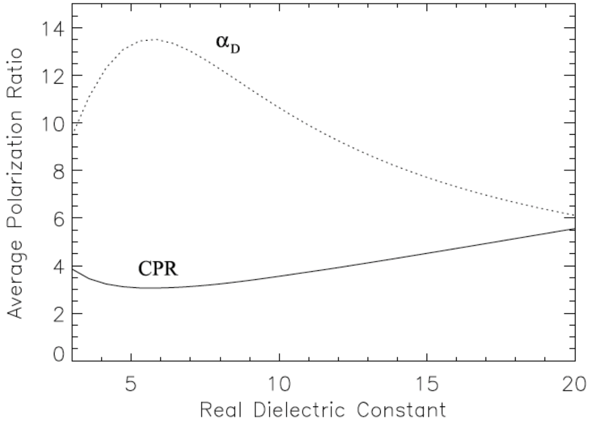
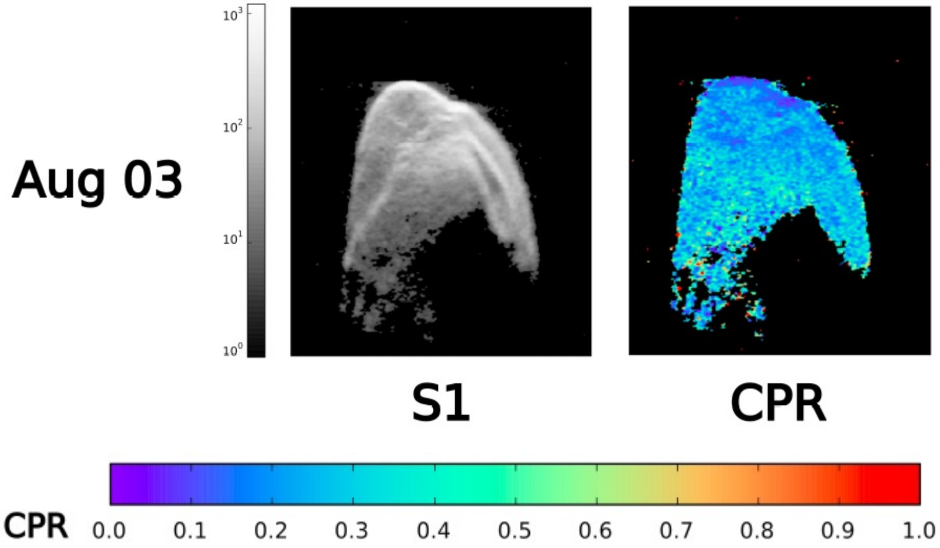
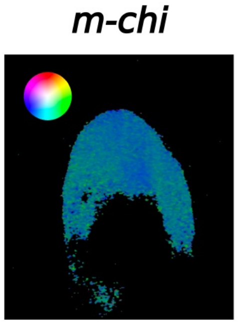
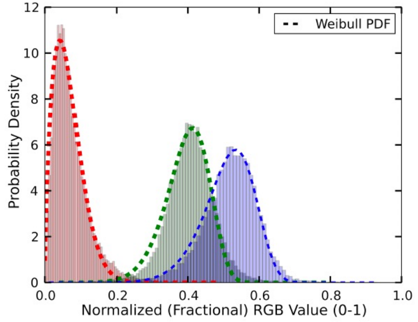


Figure 7. Circular polarization ratio (solid curve) and α_D, the ratio of HH-polarized to VV-polarized backscatter (dotted line), averaged over a distribution of randomly oriented dihedral facet pairs, as a function of the real dielectric constant of the facets.

1999 JM8 (P type)



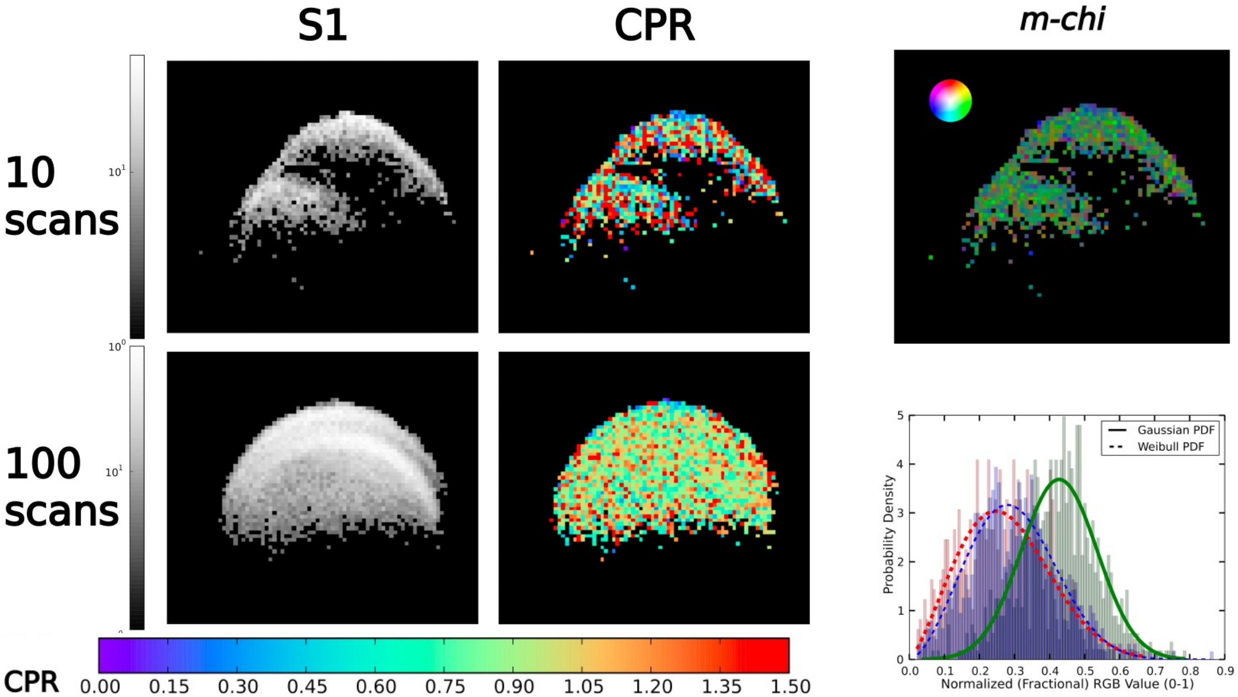




Low CPR all over, OC (blue) dominates

[Hickson et al. 2020]

33342 1998 WT24 (E type)

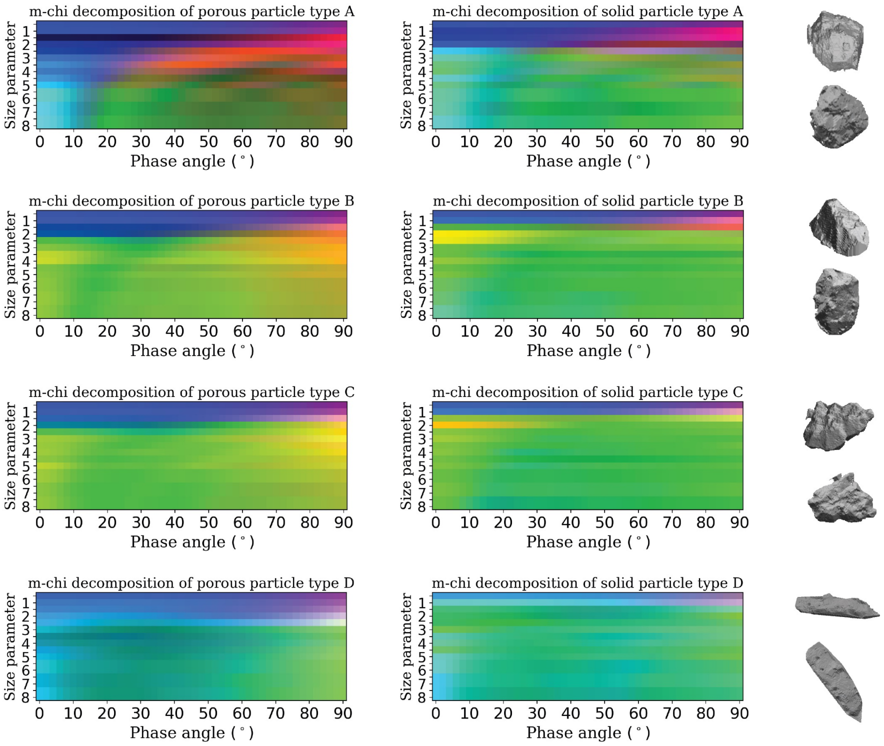


High CPR all over, SC (red) dominates: due to the wavelength-scale particles?

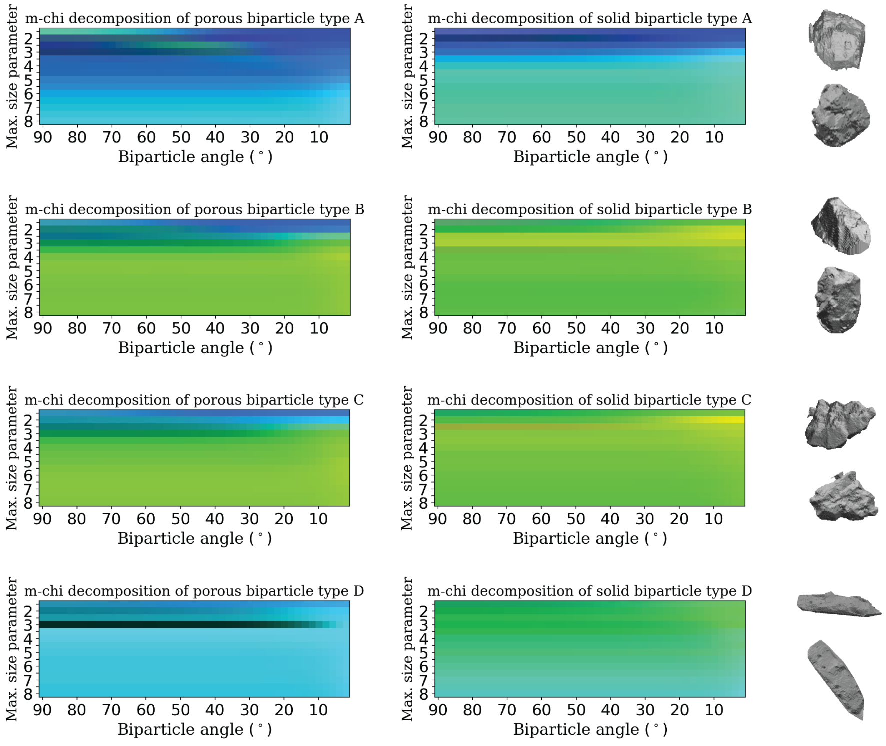
[Hickson et al. 2020]

M-chi decomposition of individual particles

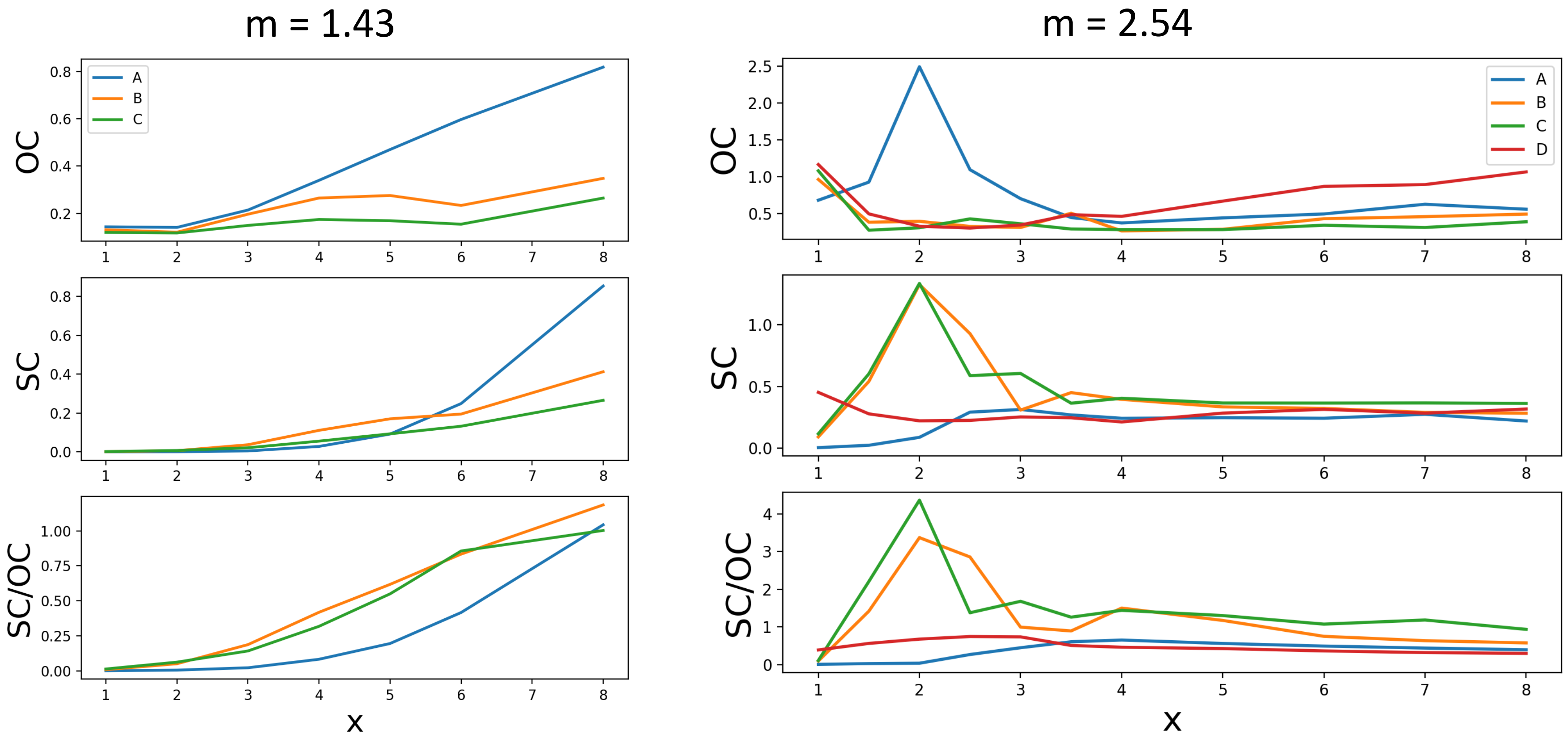
Single scattering



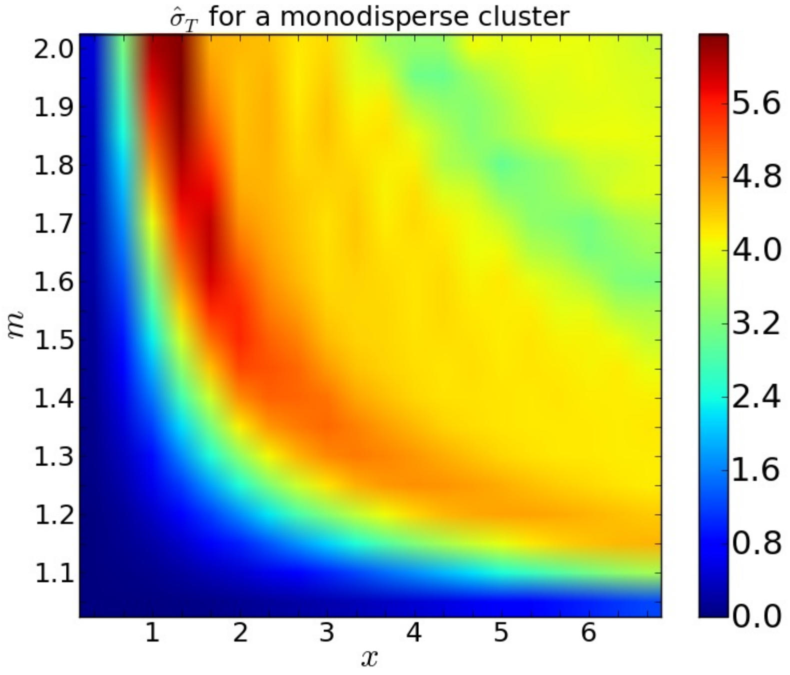
Double scattering

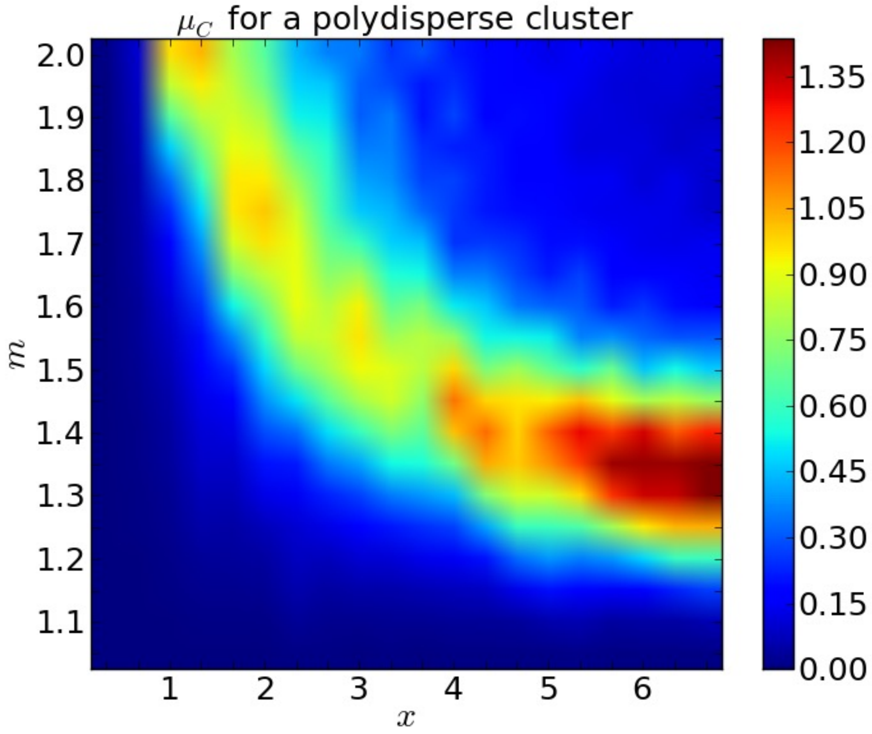


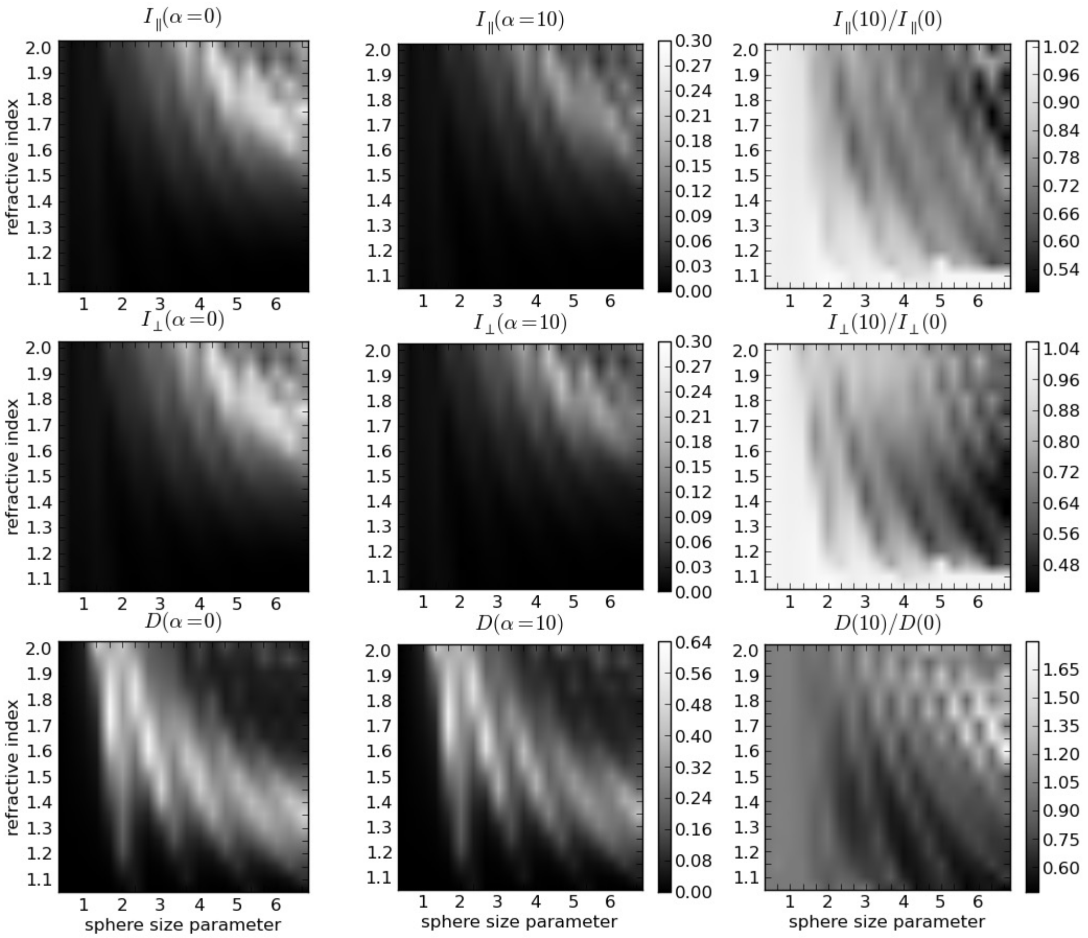
Backscattering as a function of size parameter



Backscattering as a function of size parameter and refractive index







$I_{\parallel}(\alpha=0)$
$I_{\parallel}(\alpha=10)$
$I_{\parallel}(10)/I_{\parallel}(0)$
$I_{\perp}(\alpha=0)$
$I_{\perp}(\alpha=10)$
$I_{\perp}(10)/I_{\perp}(0)$
$D(\alpha=0)$
$D(\alpha=10)$
$D(10)/D(0)$
refractive index
sphere size parameter